This experimental verification of the mechanism behind receptivity to convected disturbances is a step toward the still-unrealized goal of transition criteria, which include free-stream disturbance characteristics. Current prediction techniques do not take the free-stream disturbance environment into account and so miss an important aspect of the problem.

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Evolution of Strained Plane Wakes

Michael M. Rogers

Turbulence models currently have difficulty predicting the response of turbulence to additional strains, such as those arising in the flow over a multicomponent airfoil designed to produce high lift. In particular, as the turbulent wake of an upstream airfoil component encounters the pressure gradient produced by a downstream component, it is strained. The response to this strain is poorly predicted by existing turbulence models.

In order to provide insight into the behavior of such flows and to provide a database to aid turbulence modelers, several direct numerical simulations of strained plane wakes have been generated. These simulations are made in a reference frame moving with the free-stream velocity outside the wake and thus they evolve in time. Such temporally evolving flows are computationally simpler to generate and therefore it is possible to achieve higher Reynolds numbers and more realistic turbulence. In the limit of small wake deficits the equations governing the temporally evolving problem are identical to those describing a spatially evolving flow, such as that of a wake in an adverse pressure gradient.

Previous direct numerical simulations of unstrained wakes have been used to generate the initial conditions for the strained wake computations. Once the unstrained wake reaches an apparently self-similar state, the strain is applied to generate the strained wake cases. Six different plane strain geometries have been applied to the wake, with the directions of compression and expansion associated with the strain being aligned with the coordinate axes. The case with compression in the streamwise direction and expansion in the cross-stream (inhomogeneous) direction corresponds to that of a wake developing in the presence of an adverse pressure gradient.

Analysis shows that there is a possible self-similar state for wakes subjected to strain applied at a constant rate. Both the peak velocity deficit of the wake and the wake width are predicted to evolve exponentially in time, with the exponent in both cases being equal to half of the difference between the cross-stream and streamwise total strains. All the Reynolds stresses are predicted to scale with the square of the peak velocity deficit in this self-similar state.

The simulated flows typically do not evolve according to this self-similar solution, although the wake velocity deficits and widths do change exponentially. The wake width in flows that are compressed in the cross-stream direction approaches a constant, whereas it increases exponentially at the same rate as the global strain in flows that are expanded in the cross-stream direction (see figure). For flows in which the cross-stream direction is unstrained the wake spreads at a rate that is similar to the unstrained case. For the case that is analogous to a wake developing in an adverse pressure gradient this is consistent with the rate predicted by the self-similar analysis, and indeed this case does appear to be evolving in accord with the predicted self-similar solution.

The wake mean velocity profile is largely unaffected by the geometry of the strain, remaining approximately Gaussian throughout the flow evolution in all cases. The behavior of the Reynolds stresses, however, varies dramatically, depending on the strain geometry and on whether the global mean strain produces or destroys a particular Reynolds stress component. In most cases (although not in the adverse pressure gradient case), the mean shear

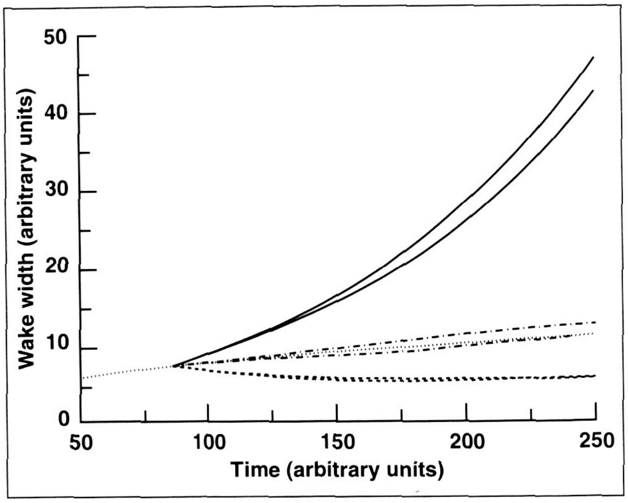

Fig. 1. The evolution of wake widths for a turbulent wake subjected to various plane strains. Solid lines denote flows stretched in the cross-stream direction; dashed lines, flows compressed in the cross-stream direction; and chain-dotted lines, flows with no strain in the cross-stream direction. The dotted line is the result from the unstrained wake simulation.

associated with the wake is found to decay and the flow evolves toward a pure straining flow.

The combination of turbulence production through both strain and time-varying wake shear provides a difficult test case for turbulence models. All terms in the Reynolds stress balance have been computed at several times for each of the simulations and are being compared with predictions of various turbulence models. The detailed information available in the simulations will provide guidance on how to improve the existing models so that they will better predict the turbulent flow over a high-lift airfoil.

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A Model for the Limiting Piston Stroke in Vortex Ring Formation

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Many devices eject a mass of fluid either in one shot or periodically. Examples include heart valves and flapping wings. Often the goal is to maximize the volume of fluid moving as a coherent vortex ring away from the exit. M. Gharib (California Institute of Technology) used a piston to experimentally study fluid ejected from a pipe and found that the largest coherent mass of fluid was attained at a piston stroke (normalized by diameter) of 4 under a variety of circumstances, including different histories of the piston motion. For longer strokes, the mass broke up into smaller vortices and a trailing jet. He also found that this maximum stroke, when expressed as a time, corresponds to the ejection period of many biological systems, including normal hearts.

The present contribution was a simple model that predicts the limiting stroke and the associated properties of the vortex such as circulation. Reasons for insensitivity to piston motion emerge from the model, and piston motions that maximize the ejected mass were obtained.

The model is based on Lord Kelvin's (1880) result that among all vortex motions with given impulse and circulation, the steady one has maximum energy. In the present situation, one finds that after a certain critical piston stroke, one cannot keep feeding enough energy (in comparison with impulse and circulation) to maintain this maximum and so the vortex becomes unsteady. This critical value agrees with the experiments, is quite insensitive to different piston histories, and correctly predicts the slight dependencies observed experimentally. Subsequently, numerical simulations by M. Rosenfeld